A workflow and methodology for investigating vowel-to-vowel coarticulation

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`http://tiny.cc/2018-langue-workflow`

Outline

Introduction

- A workflow/methodology for studying V-to-V coarticulation.
- I won't cover how to compile word/sentence lists.
- What I will discuss is how to collect, extract and process data.
- As well as ways to visualise and analyse it.
- A discussion of generalised additive mixed models.
- All the software used here is free to download online.

Toy data

- Single female Bemba speaker.
- 93 sentences, 928 vowel tokens.
- Mainly interested in F1 (but we'll see a bit of F2 and F3).
- For simplicity's sake, I'll mostly focus on /i/.
- I don't intend this to be a polished analysis by any means.

R

- R (R Core Team 2015) is used for the majority of data processing, visualisation and statistical analysis.
- RStudio, an integrated development environment (RStudio Team 2015).
- The `tidyverse` (Wickham 2017) and `tidytext` (Silge & Robinson 2016) packages are used in data processing and visualisation.

Data collection

- PsychoPy (Peirce 2007).
- Used to present stimuli individually to participants on a screen.
- Needs a source file containing a list of stimuli.
- Can be programmed to present them in a random order.
- Keeps a record of the order each participant saw.

Forced-alignment and segmentation

- The raw sound files are cleaned up in Audacity (Audacity Team 2018).
- I use SPPAS (Bigi 2015) for forced-alignment and segmentation.
- Other forced-aligners are available:
  - FAVE (Rosenfelder et al. 2011; English only).
  - (Web)MAUS (Kisler et al. 2012).
  - Montreal Forced Aligner (McAuliffe et al. 2017).
  - EasyAlign (Goldman 2011).
  - Prosodylab-Aligner (Gorman et al. 2011).
- The outcome is a set of TextGrid files used in measurement extraction.

Preparing files for SPPAS

- To carry out forced-alignment, SPPAS needs three things:
  1. Acoustic model.
  2. Vocabulary file.
  3. Dictionary file.
- Resources are currently available for 13 languages.
- Acoustic models can be co-opted and adapted for new languages.
- The vocabulary and dictionary files can be generated from the prompt lists produced by PsychoPy.

Previous measurements extracted I

- Previous work on V-to-V coarticulation has used various measurements.
- Some studies use more than one approach depending on the focus.
- Midpoints (with or without a 20–50 ms window):
  - Manuel (1984, 1987), Magen (1997), Gordon (1999), Przezdziecki (2005), Linebaugh (2007), Cole et al. (2010), Aburre & Sandalo (2017).
- Two points:
  - Midpoint and vocalic offset (Manuel 1990).
  - V_1 offset and V_2 onset (Choi & Keating 1990).
  - Mid point and vocalic onset or offset (Mok 2011, 2012).

Previous measurements extracted II

- Three points:
  - Steady-state, vowel offset and in between (Manuel 1987).
  - Vocalic onset, midpoint and offset (Beddor et al. 2002).
- Trajectories:
  - Öhman (1966; mainly for visualisation).
  - Eleven points over a VCV sequence (Recasens 1987).
  - Every 10 ms (Recasens & Pallarès 2000).
  - Nine-point trajectories (Przezdziecki 2005).
- Other:
  - Vowel onset only (Wang & Xiong 2013).
  - Average across the entire vowel and every 50 ms over a VCV sequence (Malambe 2015).

Information extracted here

The following is extracted with a Praat (Boersma & Weenink 2018) script:

- IPU (~utterance) number.
- Start time within recording.
- Vowel and word label.
- Vowel duration.
- Average F1, F2 and F3:
  - Across the entire vowel.
  - For both halves.
  - For each third.
- F1, F2 and F3 trajectories:
  - Sampled at every 5% (which admittedly might be excessive)
  - From which point-like values can also be taken.

Trajectories and V-to-V coarticulation

- More fine-grained view than using only two or three points.
- Locate with better precision when trajectories diverge.
- Test for differences that could be obscured by mean values.
- I don’t mean to say that point-like values are invalid!

Post-processing

- Add speaker-specific metadata to the dataframe.
- Tag each vowel with its syllable number within the word.
- Label each vowel token with its flanking vowels.
- Tag tokens with any other information you might want.
- Normalise formant values within speaker (Lobanov 1971) using the `scale()` function from base R.
- Save point-like formant values into one dataframe.
- Convert formant trajectories from an untidy wide format to a tidy long formant and save into a second dataframe.

Data visualisation

- See which vowel combinations we have in the data.
- Plot the vowel space (i.e. F2 against F1).
- Box or violin plots of formant values.
- Plot F3-F2 as a proxy for rounding (Stevens 2000:291).
- Plot formant trajectories (variously facetted and colour-coded).

Vowel combinations within words

	a	**e**	**i**	**o**	**u**
a	104	64	31	13	26
e	41	21	18	12	25
i	60	18	32	11	17
o	20	3	2	9	0
u	53	21	12	13	37

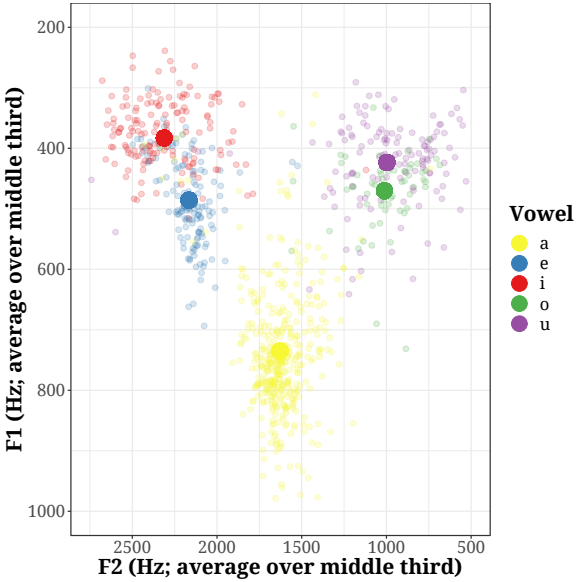
Left-hand vowels in rows; right-hand vowels in columns.

Vowel combinations within IPUs

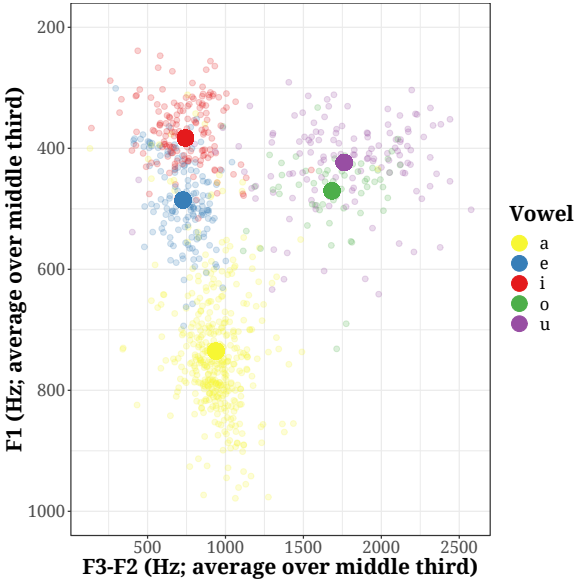
	a	**e**	**i**	**o**	**u**
a	153	70	80	16	43
e	56	21	20	14	26
i	67	18	32	11	19
o	29	5	3	9	1
u	56	21	12	13	39

Left-hand vowels in rows; right-hand vowels in columns.

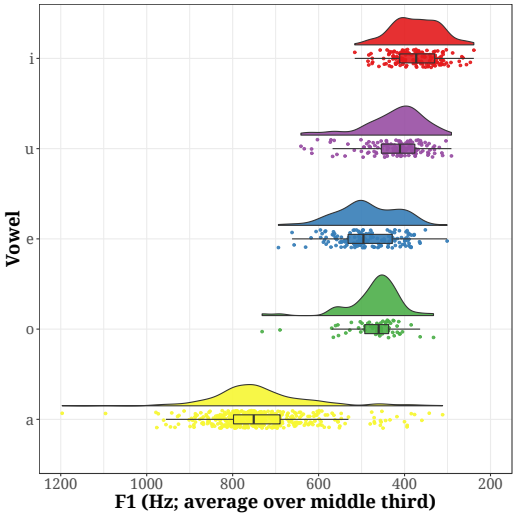
Plot of F2 against F1

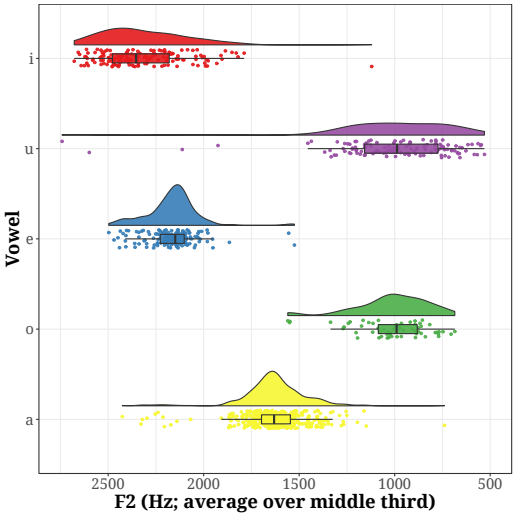


Plot of F3-F2 against F1

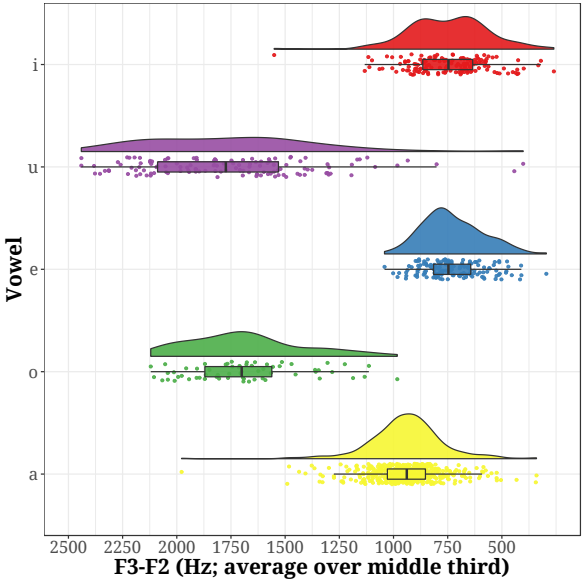


Plots of F1 and F2

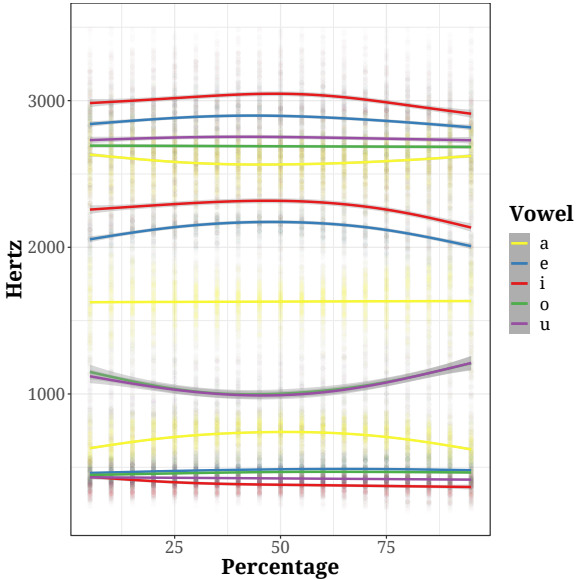




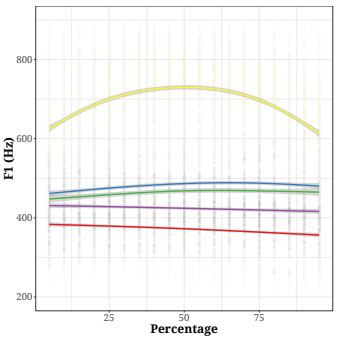
Plot of F3-F2

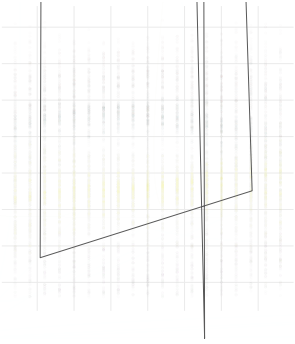

Vowel
i
u
e
o
a
2500
2250
2000
1750
1500
1250
1000
750
500
F3-F2 (Hz; average over middle third)

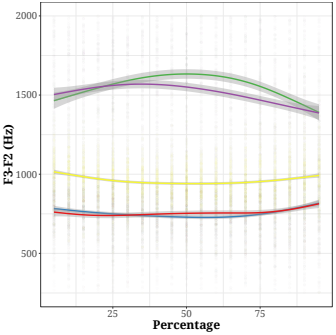
F1, F2 and F3 trajectories



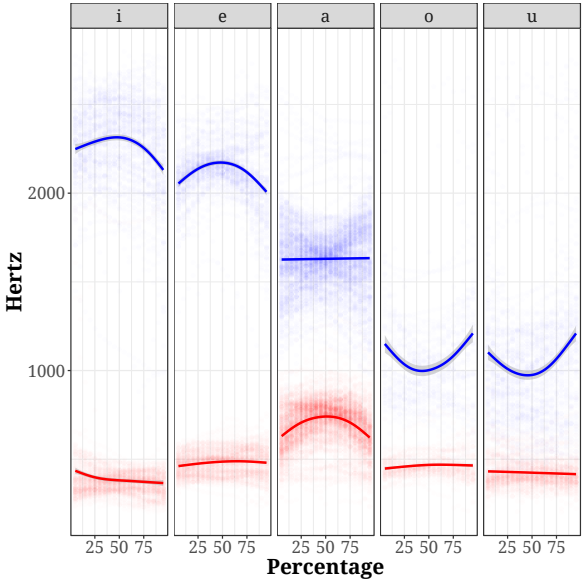
F1, F2 and F3-F2 trajectories



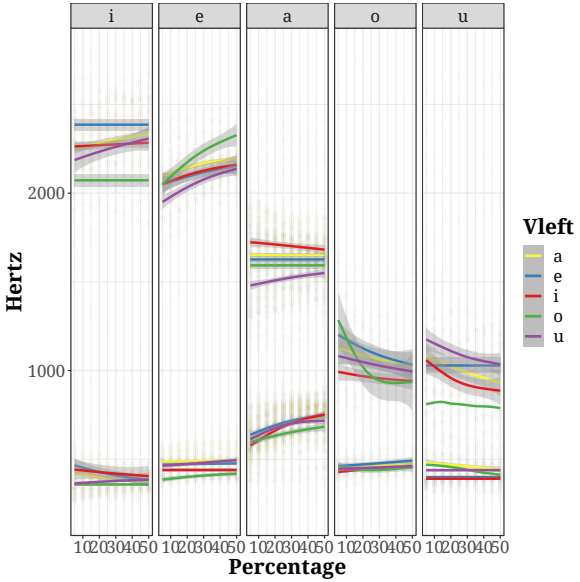




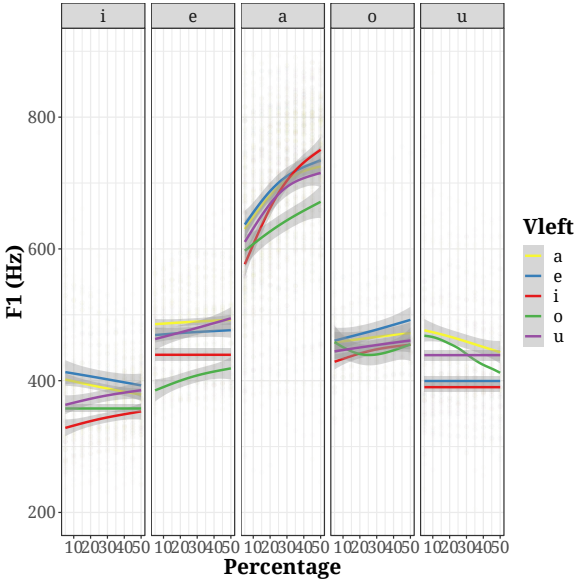
F1 and F2 trajectories



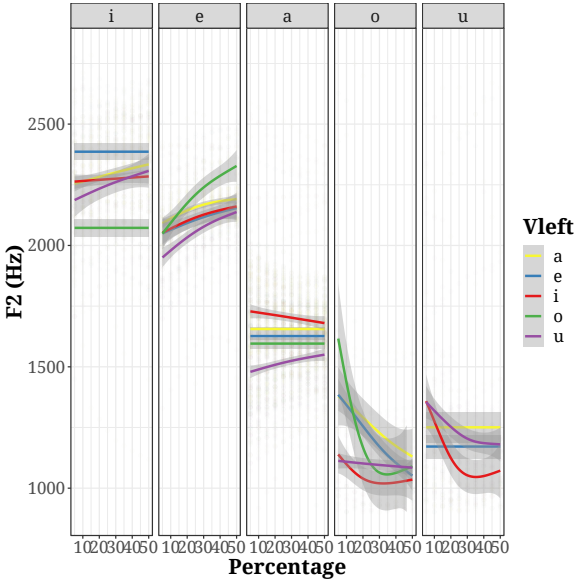
F1 and F2 trajectories by left-hand vowel



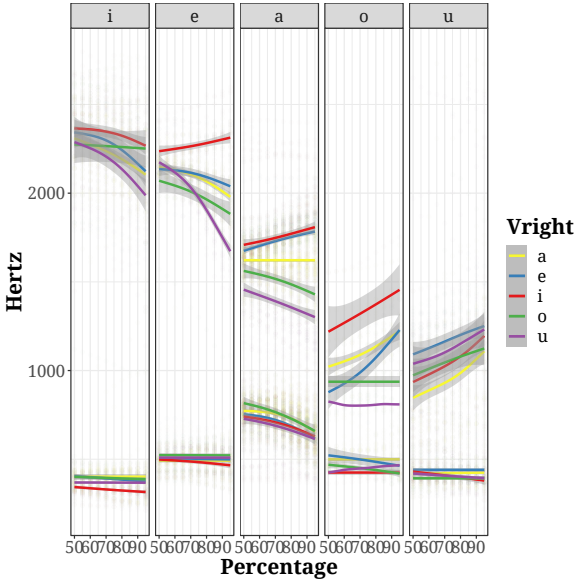
F1 trajectories by left-hand vowel



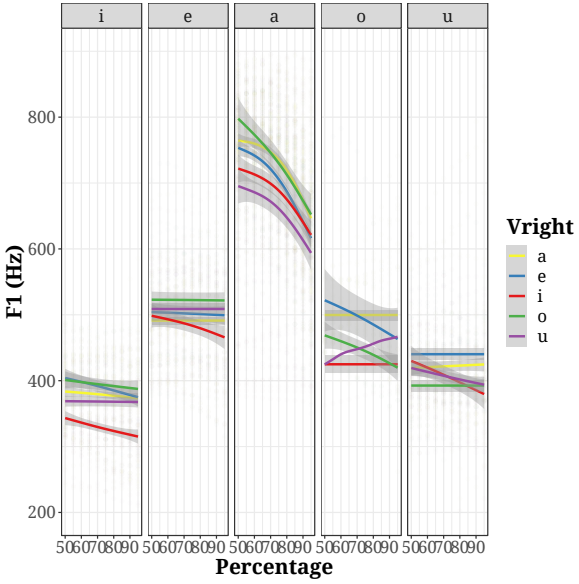
F2 trajectories by left-hand vowel



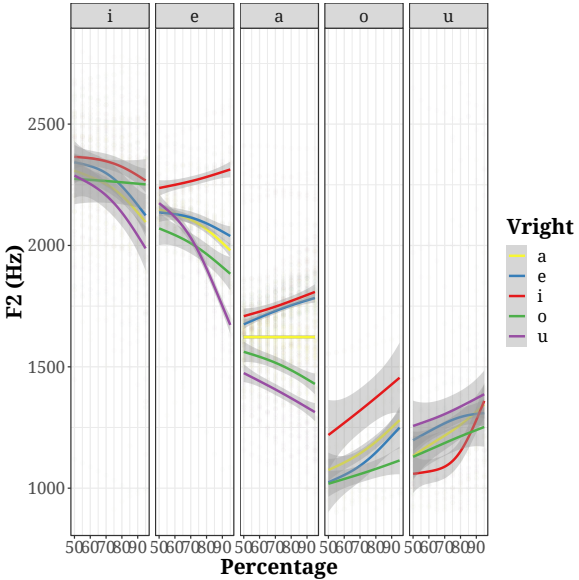
F1 and F2 trajectories by right-hand vowel



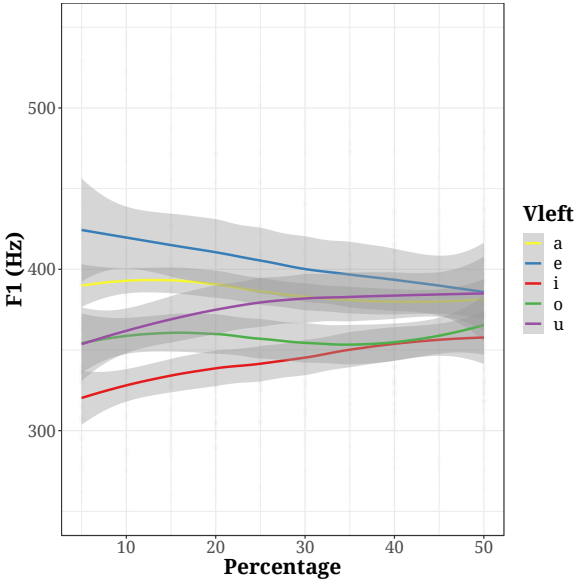
F1 trajectories by right-hand vowel



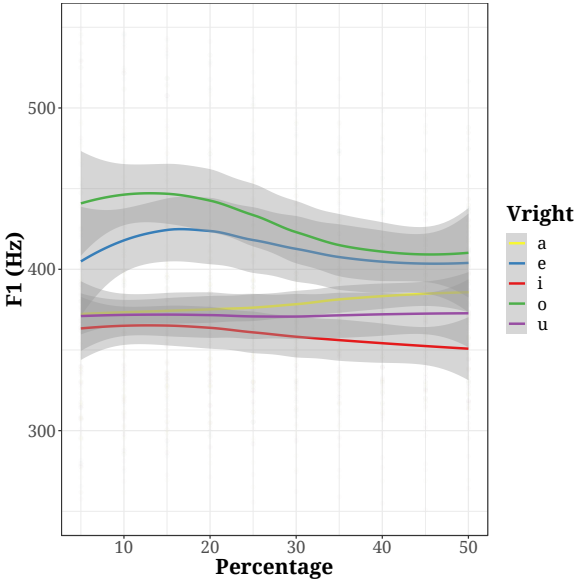
F2 trajectories by right-hand vowel



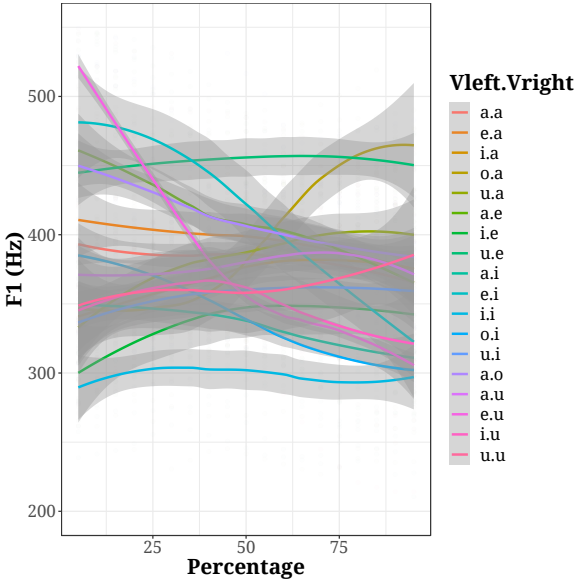
F1 trajectories for /i/ by left-hand vowel



F1 trajectories for /i/ by left-hand vowel



F1 trajectories for /i/ by left-hand vowel



Previous statistical approaches

- Some variety of ANOVA, e.g. one-way or repeated measures, is most popular (Manuel 1984, 1987, 1990, Choi & Keating 1990, Magen 1997, Gordon 1999, Recasens & Pallarès 2000, Beddor et al. 2002, Przezdziecki 2005, Linebaugh 2007, Mok 2011, 2012, Wang & Xiong 2013).
- Cole et al. (2010) use both ANOVA and linear regression.
- Recasens (1987) and Malambe (2015) use t-tests.
- Aburre & Sandalo (2017) use mixed-effects linear regression.

Repeated measures ANOVA

- Time must be treated as categorical rather than continuous.
- Differing numbers of time intervals are not allowed.
- Most importantly, does not capture non-linearities.

Possibilites for dynamic data

- SS-ANOVA.
- FPCA.
- GAMMs.
- (Among others.)

SS-ANOVA

- Smoothing spline ANOVA (Wahba 1990, Gu & Wahba 1993, Gu 2002).
- Used in ultrasound tongue imaging studies (see Davidson 2006, 2012).
- Not used in V-to-V coarticulation, as far as I can tell.
- Used to indicate whether the shapes of multiple curves are significantly different from each other.
- Does not support random effects (unlike GAMMs).

(F)PCA

- Principal component analysis (Jolliffe 2002, Johnson 2008).
  - Can be used with ultrasound tongue contours (e.g. Harshman et al. 1977, Slud et al. 2002, Stone 2005, Turton 2014, Bennett et al. to appear).
- Functional principal component analysis (Ramsay & Silverman 2005).
  - Can be used with formant trajectories (see e.g. Gubian et al. 2015).
  - Allows time normalisation and landmark registration.
- Require use of further statistical analysis (e.g. with linear models).
- As far as I'm aware, neither has been used for V-to-V coarticulation.

GAMMs I

- Generalised additive mixed models (Hastie & Tibshirani 1990, Wood 2006, Zuur et al. 2014).
- Ideal for analysing dynamic speech data (Sóskuthy 2017).
- Becoming ever more popular in phonetics (Kösling et al. 2013, Fox & Mielke 2016, Wieling et al. 2016, Ünal-Logacev et al. 2017, Strycharczuk & Scobbie 2017, Kirkham & Nance 2018, Strycharczuk & Sebregts 2018, Al-Tamimi 2018, Bailey & Nichols 2018, Sóskuthy et al. 2018).
- Plenty of help for using them with linguistic data (Baayen et al. 2016, 2017, Winter & Wieling 2016, Sóskuthy 2017, Wieling in press).
- Analysis and visualisation in R using the `mgcv` (Wood 2018) and `itsadug` (van Rij et al. 2017) packages.

GAMMs II

- Capture non-linearities (not possible with linear regressions):
  - Smooth terms as well as intercepts and slopes.
  - Can detect differences in shape as well as height of trajectories.
- Less over- or undersmoothing than SS-ANOVA.
- Random smooths and autoregressive error models can be used to combat autocorrelation.
- Can test for both overall and local differences between curves.
- Disadvantages: more complex, computationally intensive, less straightforward to test for significance.
  - Tests for significance: model summary, plotting smooths, difference smooths, model comparison (see Sóskuthy 2017:16–21).

Quick test case

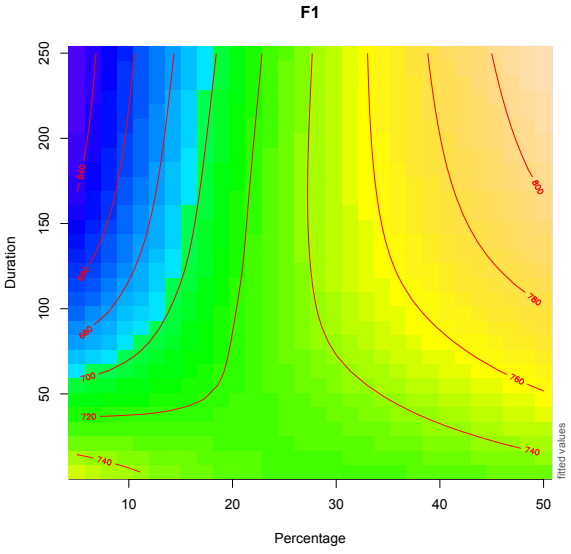
Let's investigate the effect of adjacent vowels on the F1 of target vowels:

- Parametric term and difference smooth for the interaction of target and adjacent vowels.
- Smooths for percentage, duration and their interaction.
- By-trajectory random smooths.
- (We would also include by-speaker random smooths if we had more than speaker.)

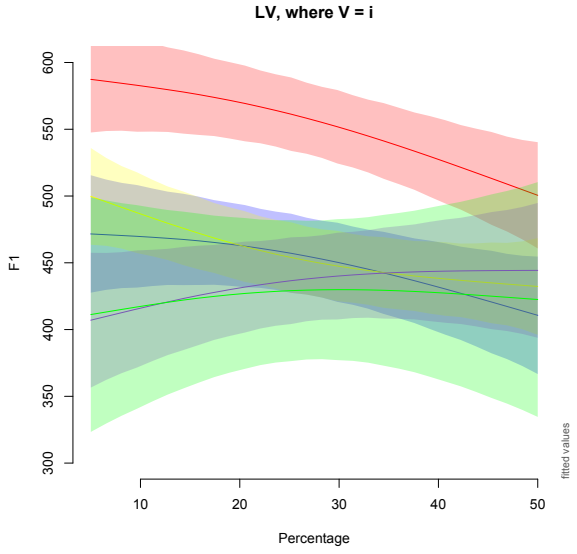
Model summary (Vleft)

```
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  690.149      6.285 109.801  < 2e-16 ***
## LVo.a        -65.798      8.833  -7.450 1.02e-13 ***
## LVe.a         19.962      6.728   2.967  0.00301 **
## LVu.a        -17.010      6.959  -2.444  0.01453 *
## LVi.a         -8.096      6.512  -1.243  0.21381
## LVP.a         99.743      7.137  13.976  < 2e-16 ***
## LVa.o       -260.258     11.672 -22.298  < 2e-16 ***
## LVo.o       -263.641     16.025 -16.452  < 2e-16 ***
## LVe.o       -250.313     12.527 -19.982  < 2e-16 ***
## LVu.o       -238.752     12.983 -18.389  < 2e-16 ***
## LVi.o       -254.057     14.369 -17.681  < 2e-16 ***
## LVa.e       -197.977      6.360 -31.130  < 2e-16 ***
```

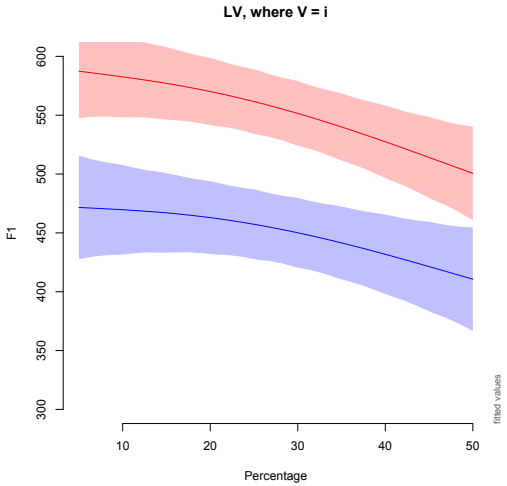
Heatmap (Vleft)

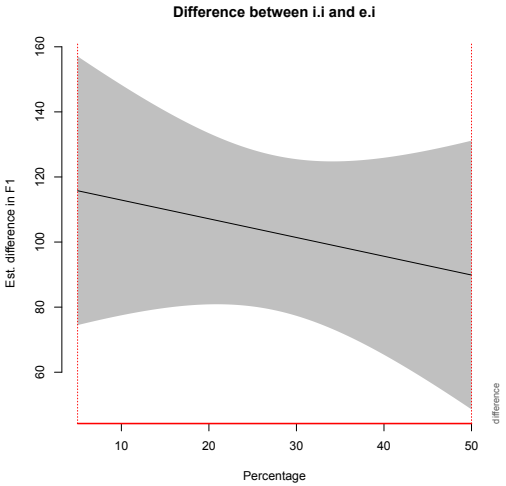


Plotting differences (Vleft)

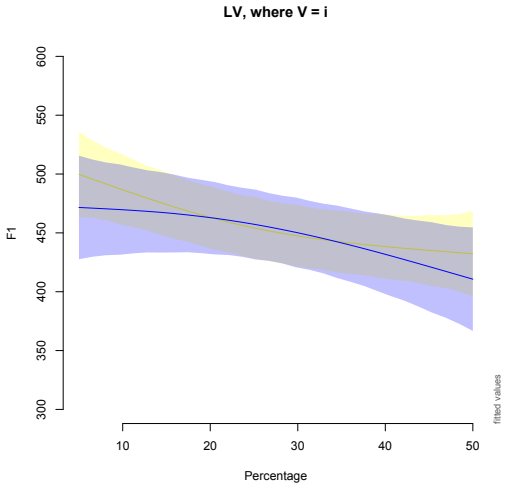


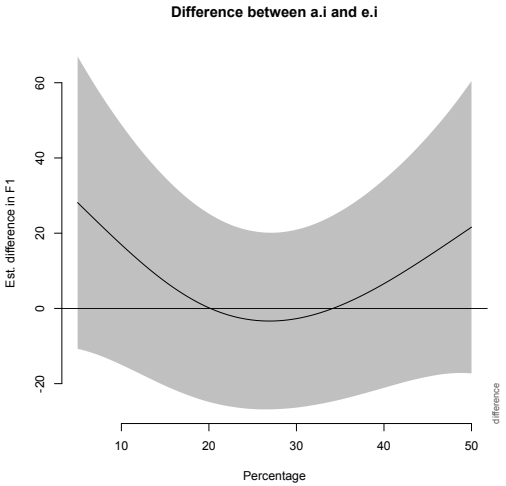
Plotting differences (Vleft)



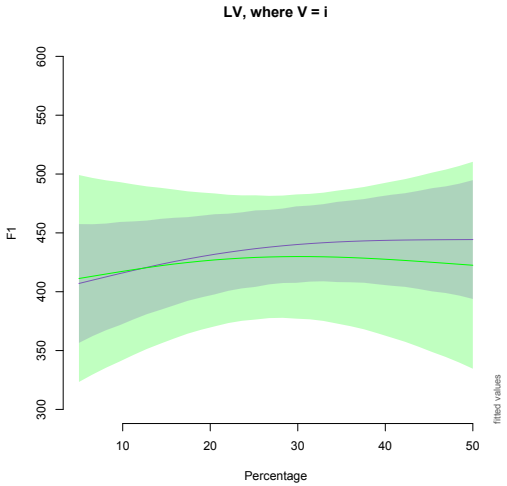


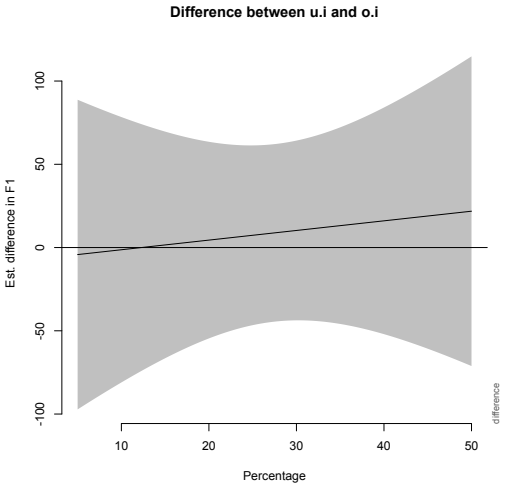
Plotting differences (Vleft)



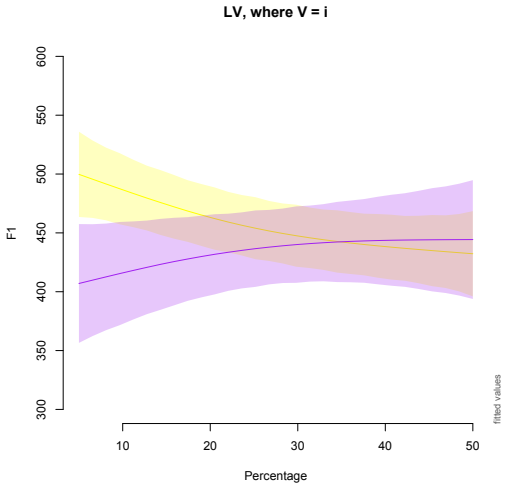


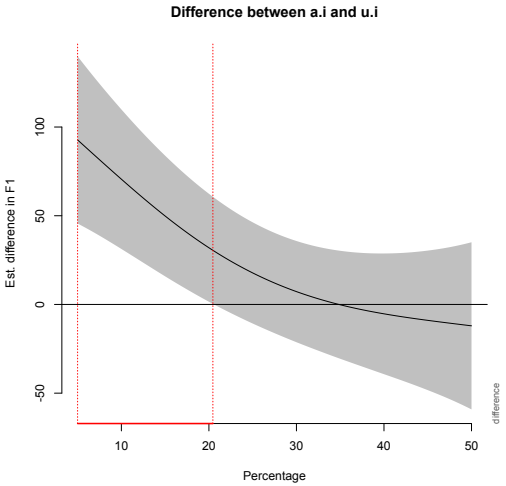
Plotting differences (Vleft)





Plotting differences (Vleft)





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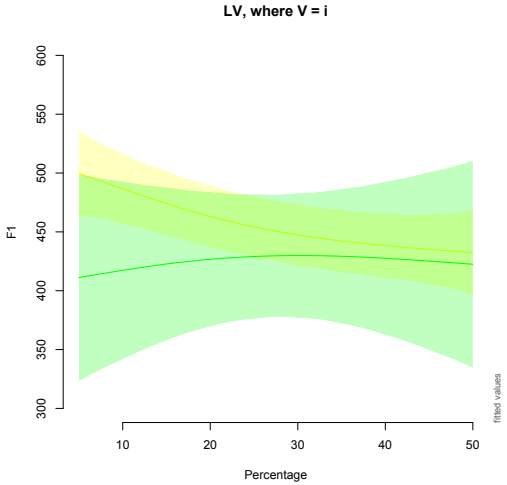

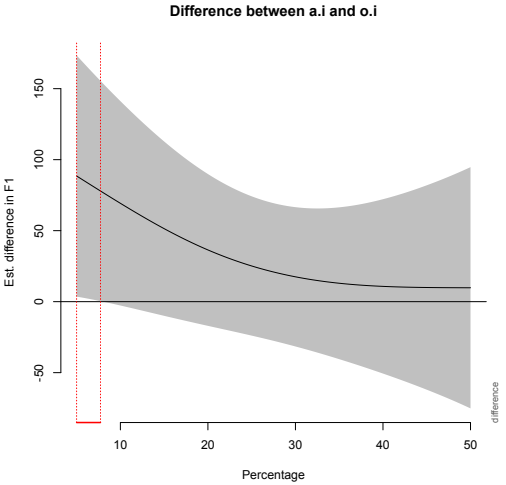

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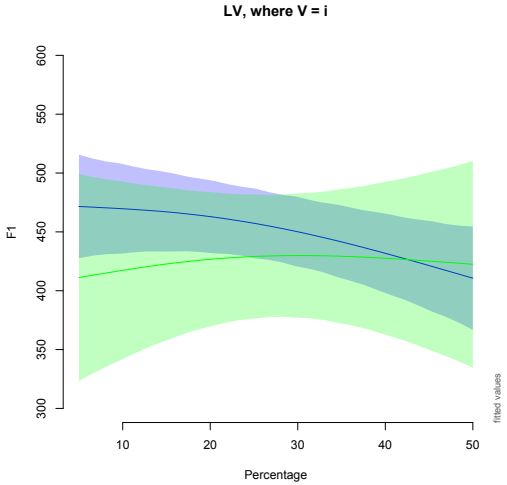

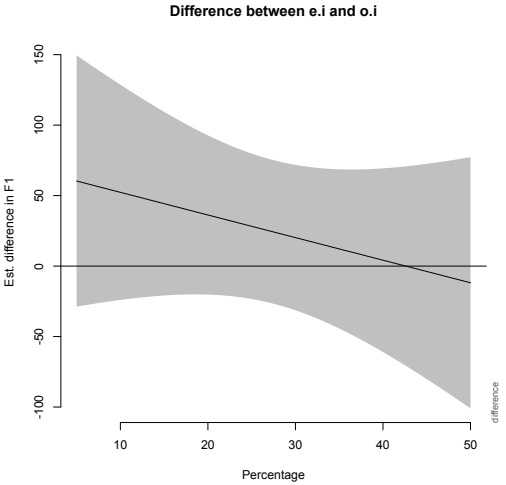

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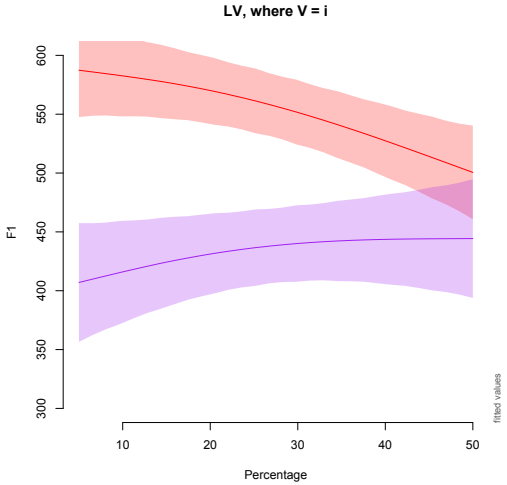
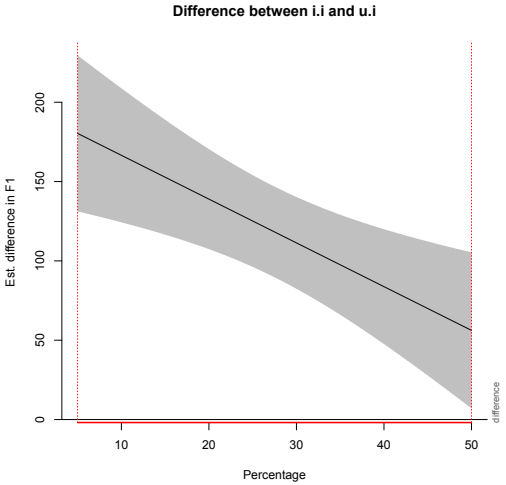
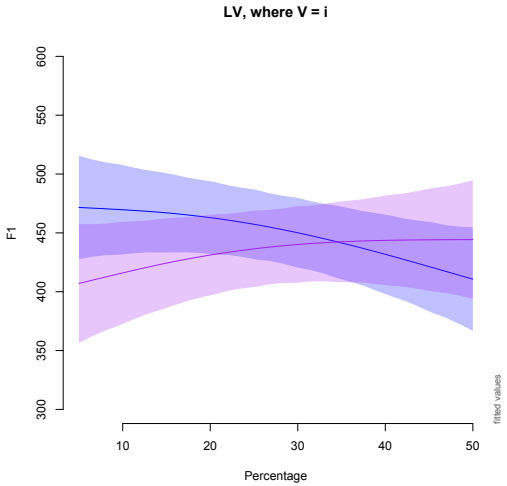
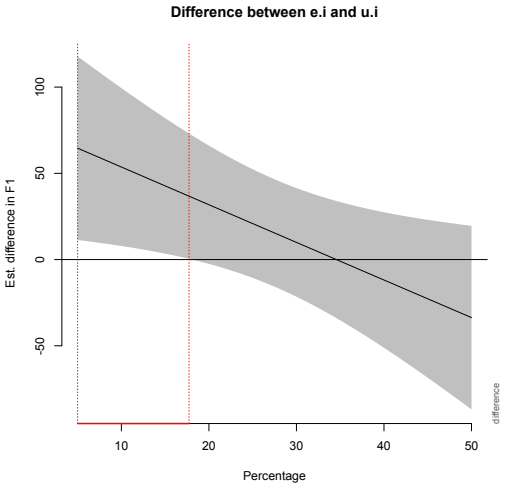




Plotting differences (Vleft)

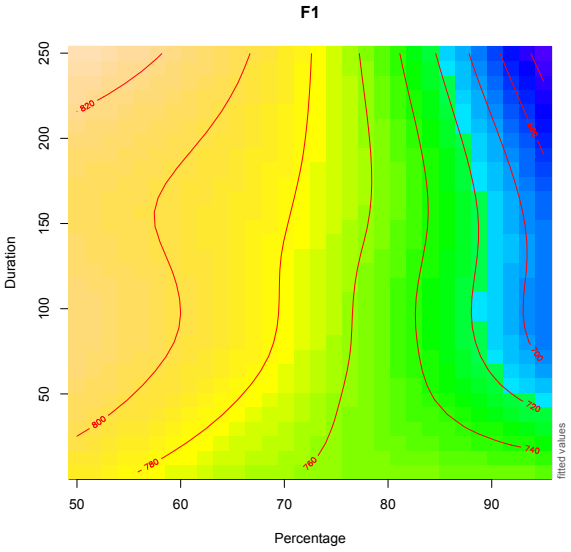




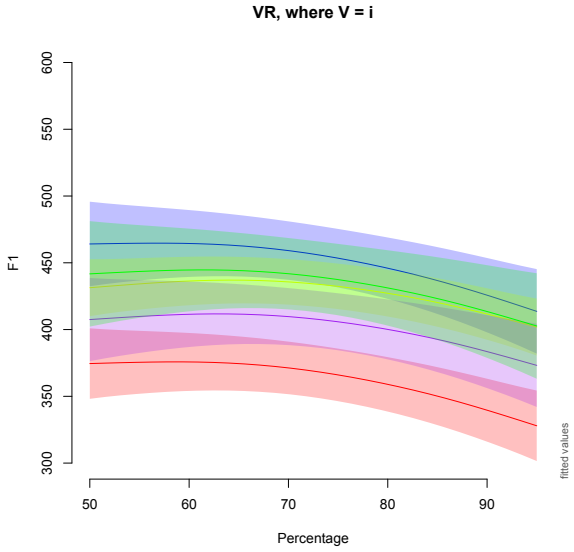
Model summary (Vright)

```
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  727.485      5.286 137.631  < 2e-16 ***
## VRo.a       -242.770      7.664 -31.675  < 2e-16 ***
## VRe.a       -228.769      5.772 -39.632  < 2e-16 ***
## VRu.a       -315.528      5.587 -56.471  < 2e-16 ***
## VRi.a       -337.420      5.335 -63.247  < 2e-16 ***
## VRa.o         28.642      9.738   2.941 0.003277 **
## VRo.o       -316.321     13.681 -23.121  < 2e-16 ***
## VRe.o       -235.295     10.463 -22.487  < 2e-16 ***
## VRu.o       -308.343     10.995 -28.045  < 2e-16 ***
## VRi.o       -331.823     12.285 -27.010  < 2e-16 ***
## VRa.e        -18.410      5.291  -3.479 0.000505 ***
## VRo.e       -247.149     18.313 -13.496  < 2e-16 ***
```

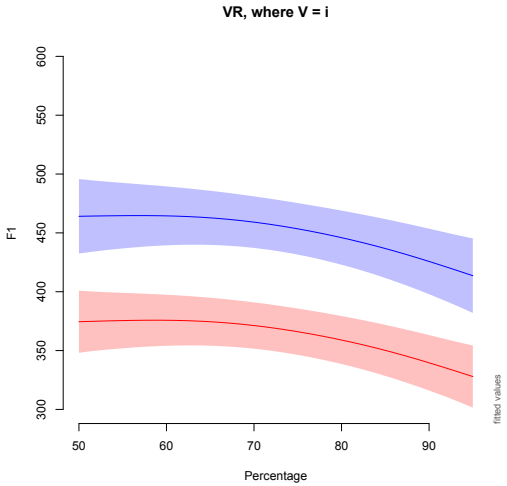
Heatmap (Vright)

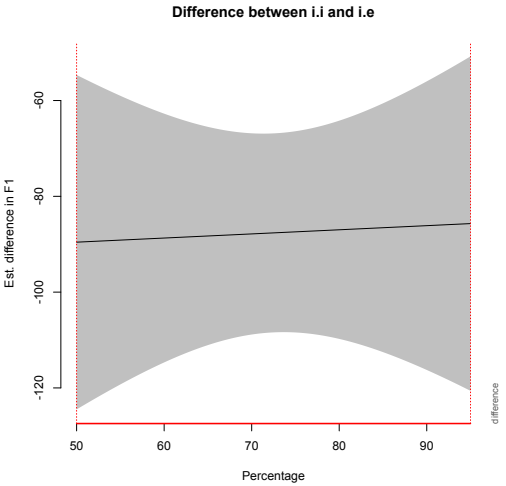


Plotting differences (Vright)

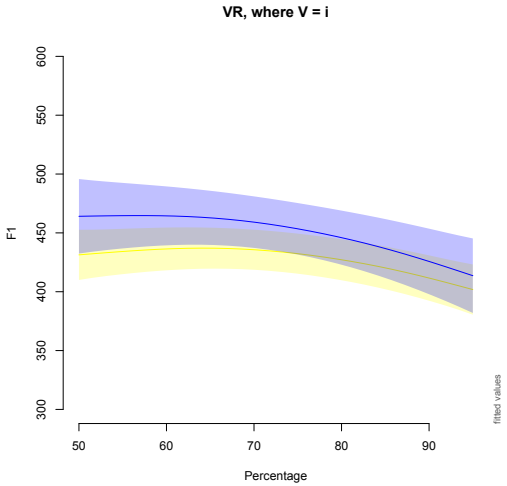


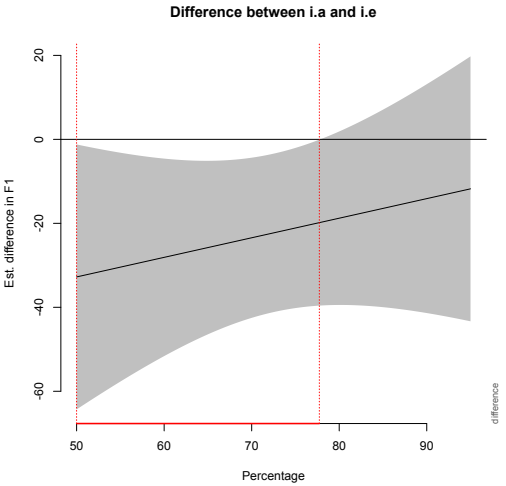
Plotting differences (Vright)



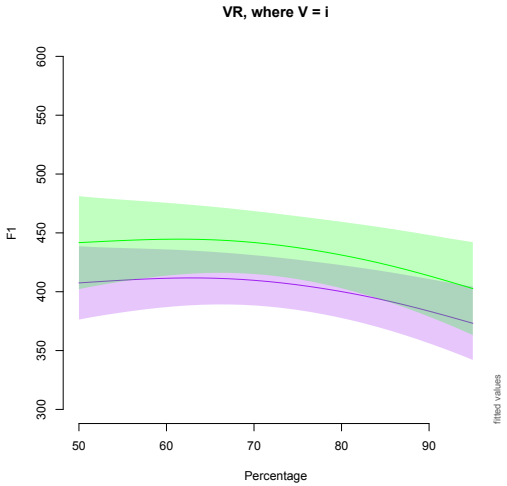


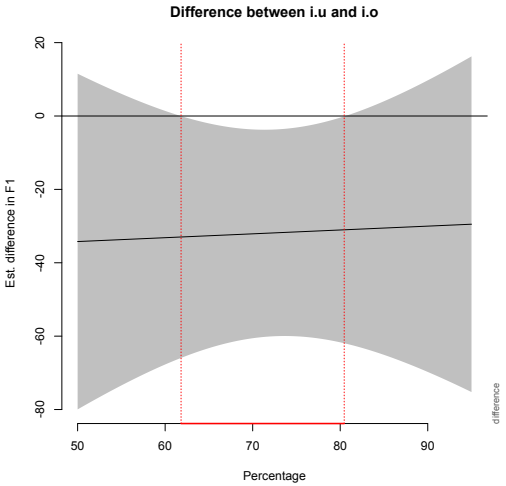
Plotting differences (Vright)



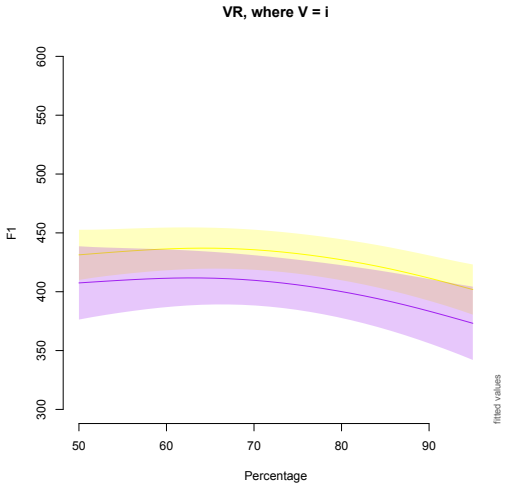


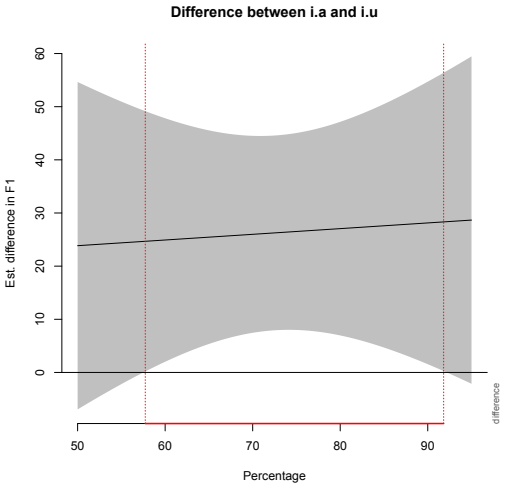
Plotting differences (Vright)



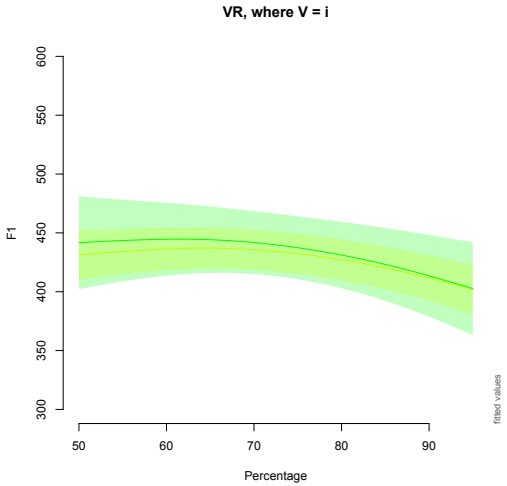


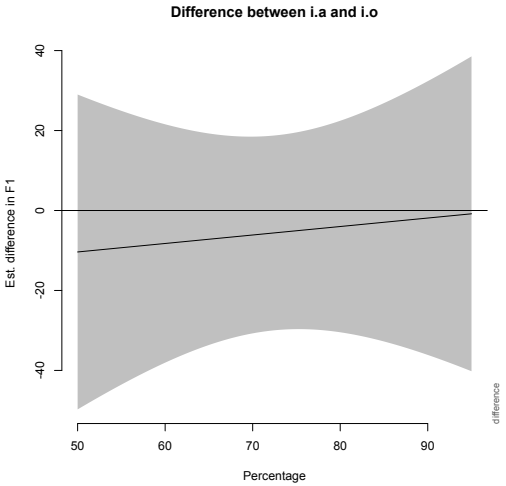
Plotting differences (Vright)



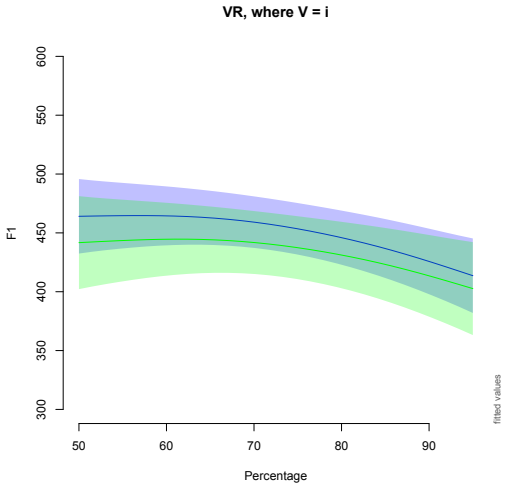


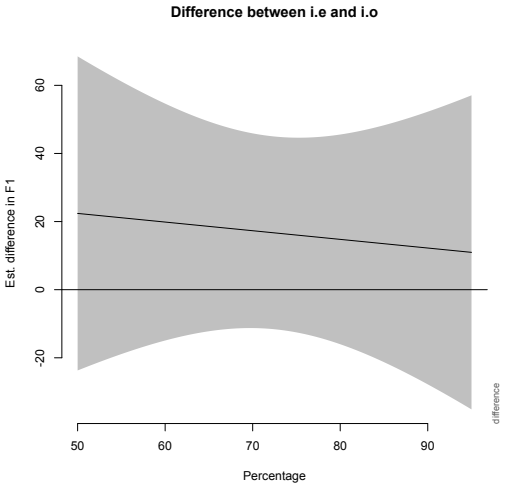
Plotting differences (Vright)



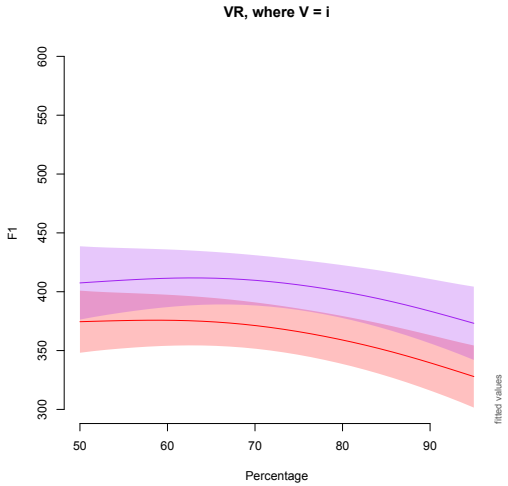


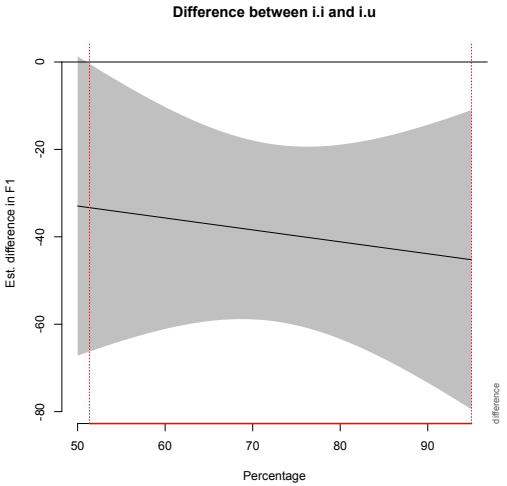
Plotting differences (Vright)



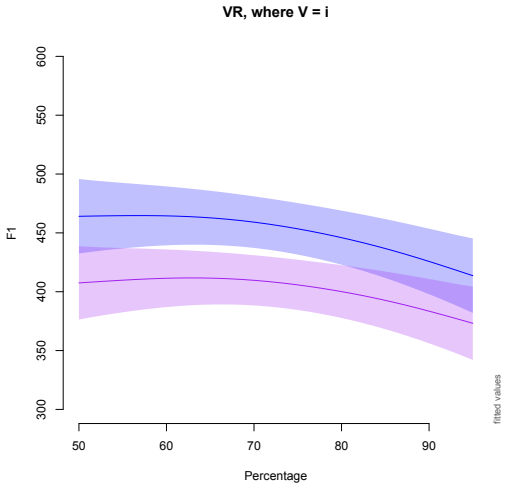


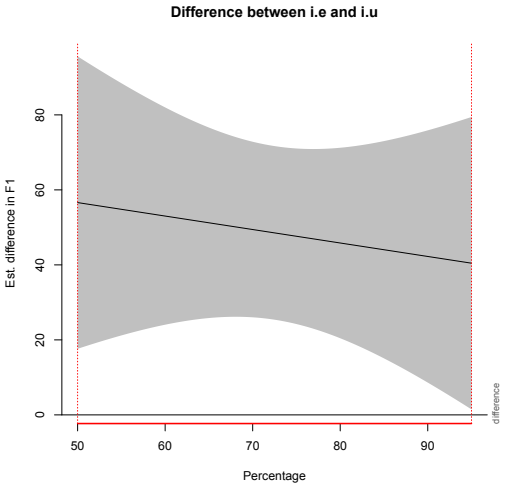
Plotting differences (Vright)





Plotting differences (Vright)





Model comparison I

- Model comparison (likelihood ratio test) with `itsadug::compareML`.
- Fit nested model which excludes parametric term and difference smooth term.
  - Models should be fit with `method="ML"` for model comparison.
- This will tell you whether the additional terms significantly improve the fit of the model.

Model comparison II

```
##          Model    Score Edf Difference    Df  p.value Sig.
## 1 f1.vleft.null 60644.60   5
## 2     f1.vleft 57549.55  92   3095.052 87.000  < 2e-16  ***
```

```
##           Model    Score Edf Difference    Df  p.value Sig.
## 1 f1.vright.null 60644.60   5
## 2     f1.vright 57549.55  92   3095.052 87.000  < 2e-16  ***
```

Bonus material

- Atom (GitHub, Inc. 2011) for writing Praat scripts; syntax highlighting with the `language-praat` package (Coretta 2016).
- Windows-only alternative: Notepad++ (Ho 2003) with a plug-in for syntax highlighting (Sadowsky 2014).
- Integrate Praat scripts into R code with `speakr` (Coretta 2017a,b).
- Check and adjust formants with Formant Editor (Sóskuthy 2015).
- Use different formant settings for each vowel to reduce tracking errors (see e.g. Escudero et al. 2009, Kirkham & Nance 2017).
- Automatically detect phonetic variation with forced-alignment software (cf. Yuan & Liberman 2011, Milne 2014, Bailey 2016).

Summary

- I’ve shown you a streamlined (and easily adaptable) workflow.
- Trajectories are a worthwhile way of investigating V-to-V coarticulation.
- Previous statistical tests may not necessarily be appropriate for them.
- GAMMs are a useful tool for time-series phonetic data.

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- George Bailey, Fernanda Barrientos Contreras and Stefano Coretta for help with Praat, R and SPPAS.
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